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NOVEL ELECTRON BEAM CATHODE

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Final Report

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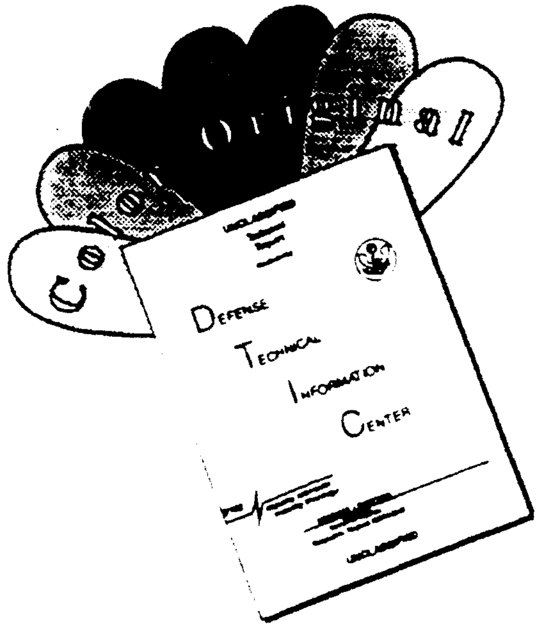

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13. ABSTRACT *(Maximum 200 words)*

Experiments have been conducted during the past year to develop an electron beam cathode which is capable of producing a moderate perveance beam for several microsecond pulse lengths and is not susceptible to diode closure. The requirements, successfully met by this salt-based cold emission cathode, include operating in modest vacuums of 10^{-5} Torr, voltages $\leq$ 160 kV, and the ability to generate solid or annular cross section space-charge-limited electron beams. Data on the operating performance of this salt cathode and streak photographs showing the uniformity of the emission of the electron beam are presented. Comparisons of this salt cathode will be made with other electron beam cathode materials.

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1.0 INTRODUCTION

During the past 10 years there has been research on various technologies which use high current electron beams [Ref. 1]. These electron beams may be generated by various mechanisms, i.e. thermionic emission, photo-emission, field emission, or explosive emission. However, none of these techniques allow generation of electron beams with current densities of tens to hundreds of Amperes per square centimeter (A/cm^2) while the electrons are accelerated through hundreds of kilovolts of potential, and maintain this operation for several microseconds in relatively "poor" vacuum systems which is typical of pulse-power environments. Some electron beam generation techniques require special handling or auxiliary equipment which add to the complexity of the original experiment.

Experiments have been performed on an explosive emission cathode which does not suffer from diode collapse. This is the main failure encountered in explosive emission, high current electron beam accelerators. Explosive emission cathodes generate plasmas which typically have plasma ion acoustic speeds of several centimeters per microsecond (cm/μsec). This results in electron beam pulses of less than one microsecond for vacuum diodes using several centimeter anode-cathode (A-K) gaps. Previous workers tried to solve this problem by controlling the production of the cathode plasma, e.g. eliminating the water vapor as a source of relatively high velocity atomic hydrogen ions. The research reported here took another approach: change the mass of the predominant ion species in the plasma and thereby reduce the ion acoustic speed by the square root of the atomic mass of the ions. There are other sources for the plasma produced in the A-K gap, namely the anode plasma, however, the cathode plasma is a major problem in diode closure, particularly at the modest tens of A/cm^2 current densities investigated in this experiment.

This paper discusses experiments using a 6.85 cm radius Cesium-Iodide (CsI) cathode, a 4.6 cm radius velvet cathode, and a 4.6 cm radius CsI cathode. A photograph of the two CsI cathodes is shown in Figure 1.

2.0 EXPERIMENTAL MEASUREMENTS

These experiments were conducted on the Sandia CDS pulser, a gas (SF_6) insulated 5 stage Marx generator with a crowbar switch to limit the pulse length. The CDS pulser has 0.6 μF, 50 kV of energy storage per stage. The pulser was reconfigured to only use 4 stages and the voltage per stage was less than 40 kV, that is, the diode voltage was kept below 160 kV. This vacuum diode was composed of a 4 cm A-K gap, 7.5 cm radius anode screen which is 90 percent optically transparent stainless steel mesh (100 x 100 lines per inch) in an aluminum flange, and the cathode was either a 4.6 cm or a 6.85 cm radius electron emitter. The emitters used were velvet fabric stretched taut in an aluminum housing or the CsI solution applied to a carbon fiber array as shown in Figure 1. In all cases the outermost edges of the active emission surfaces were electrostatically shielded by an aluminum bushing. This corona bushing, which was painted with insulating paint (Glyptol) to inhibit field emission from its surface, served to greatly reduce the field at the edges of the active emitting surface. With this cathode configuration the observed closure phenomena were typical of the bulk surface itself, rather than resulting from anomalous processes driven by field enhancement at the cathode edge. The corona bushing also defined the electron emission area of the cathode. Aluminum spacer rings were available to allow recessing the emitter surface below the plane of the corona bushing. These rings were used to investigate electron beam emission from the glyptol painted surface of the corona bushing, and will be discussed later.

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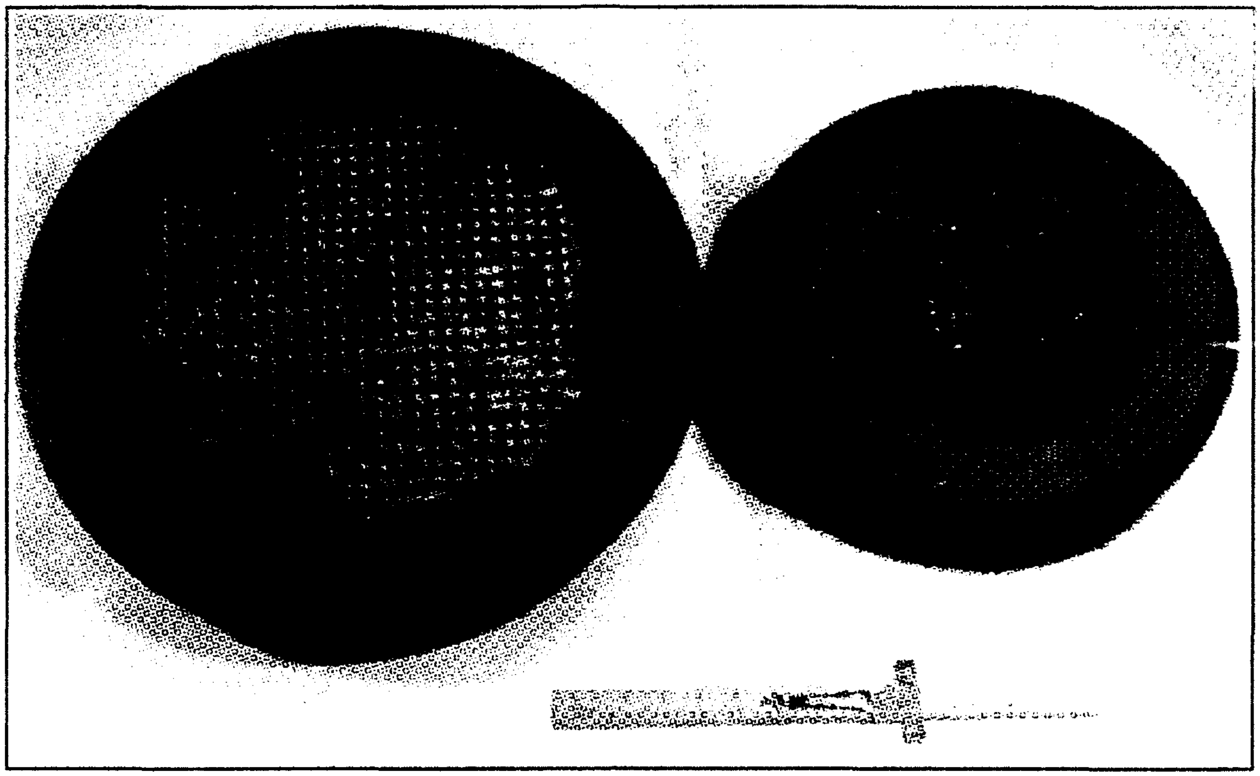

Figure 1. Examples of a 6.85 cm radius and 4.6 cm radius CsI cathode.

The crowbar switch uses a self-breaking gas switch, which is biased by a capacitive pick-off from the Marx generator. The capacitor is charged by the current flow through the cathode shank. The RC charge time determines how quickly the Marx voltage is applied across the crowbar switch plates. The switch then closes via the DC Paschen curve for SF_6. The pulse length is then directly proportional to the gas pressure within the switch while operating at a specified voltage, i.e. the pulse length varies as several tens of nanoseconds per pound per square inch of pressure. The crowbar switch was used to vary the pulse length from 100 ns to 8 µs. This range of pulse widths enabled observation of the beginning of the emission of the electron beam and the collapse of the diode gap.

Electrical and optical diagnostics were employed in monitoring this experiment. Capacitive voltage and B-dot current probe diagnostics monitored the pulse power system parameters. A streak camera monitored the time variation of the electron beam diameter via optical emission from a lucite scintillator after the beam had propagated at least 2 cm past the anode screen.

The explosive emission diodes operate at the Space-Charge Limiting or Child-Langmuir current density, which depends on the applied voltage and the geometry of the vacuum diode. The equation governing the current density for a nonrelativistic solid beam (valid for energy ≤ 500 kV) is [Ref. 2]:

$$j_{SCL}(kA/cm^2) = 2.34\,\frac{(V(MV))^{3/2}}{(d(cm))^2} \tag{1}$$

From Equation 1 one determines the beam perveance P, where the electron beam is assumed to be uniformly emitted from a circular area of radius r ($A = \pi r^2$) [Ref. 3]:

$$P = \frac{I(kA)}{(V(MV))^{3/2}} = 2.34 \frac{A(cm^2)}{(d_0(cm) - v(cm/ns)t(ns))^2} \tag{2}$$

If one plots the inverse ratio of the square root of the perveance, the slope of the curve is proportional to the closure velocity of the planar vacuum diode. Equation 2 ignores the effects of radial emission and the effects of a nonlinear diode collapse. The y-intercept of the inverse ratio of the square root of the perveance is inversely proportional to the emission area of the cathode. The experimental data indicate this is a valid description during substantial portions of the pulse duration. The emission radius and the diode closure velocity are two parameters available to fit the experimental voltage and current data. As stated above, the voltage was varied from 80 kV to 160 kV across an A-K gap of 4 cm and the current emitted varied from about 300 A to 1 kA from a 4.6 cm or a 6.85 cm radius cathode.

3.0 RESULTS

The standard cathode employed in the Split Cavity Oscillator (SCO) [Ref. 4] is a circular velvet [Ref. 5] emission surface with a rounded corona bushing painted with insulating Glyptol. The cathode is located in a 15 cm radius cylindrical aluminum vacuum vessel. The stainless steel anode screen is 7.5 cm in radius and supported by a solid aluminum plate which extends to the vacuum chamber wall. In early experiments the cathode was 6.85 cm in radius and a 5 cm aluminum mask was used to improve the SCO beam power to RF power efficiency. Later, this cathode was replaced by a 4.6 cm radius emitting surface and the aluminum mask was removed. Representative diode data are shown in Figure 2, along with the time varying diode impedance and inverse square root of the perveance. This vacuum diode with an A-K gap of 4 cm demonstrated a relatively uniform emission of electrons for a field stress on the order of 40 kV/cm. The diode closure typically was on the order of 1 cm/µs. The diode impedance was calculated based on the time dependent voltage and current. The emission area of the beam was also required, and was determined with a streak camera (Figure 3). The horizontal dark lines in the streak photo are 2 cm space fiducials on the lucite scintillator used to image the beam. The larger dark band marks the center of the beams. The photo then shows the diameter of the electron beam as a function of time as well as a qualitative measurement of current density across this diameter. The parameters from the perveance calculation indicated that the uniform emission radius was 3.6 cm rather than the geometric 4.6 cm, and the closure velocity was on the order of 2 cm/µs. The streak photo supports the observation of a smaller initial area, as is shown by the small hot spot during the turn-on of the electron beam pulse.

The velvet emitter was replaced with a graphite plate (6.85 cm radius initially). The graphite plate had holes drilled on a 0.5 cm grid, and each hole was filled with ≤ 1 cm tall carbon fiber bundles. The CsI solution was then brushed on the fibers and allowed to dry. The cathode and corona bushing were baked at 100°C for 4 hours, and then mounted in the vacuum vessel while still hot. This was done to minimize the water vapor contamination, a prime contributor to the diode closure problem due to the low atomic number (low Z) constituents. The vacuum diode was allowed to pump overnight prior to being pulsed. A series of pulses with increasing voltage or

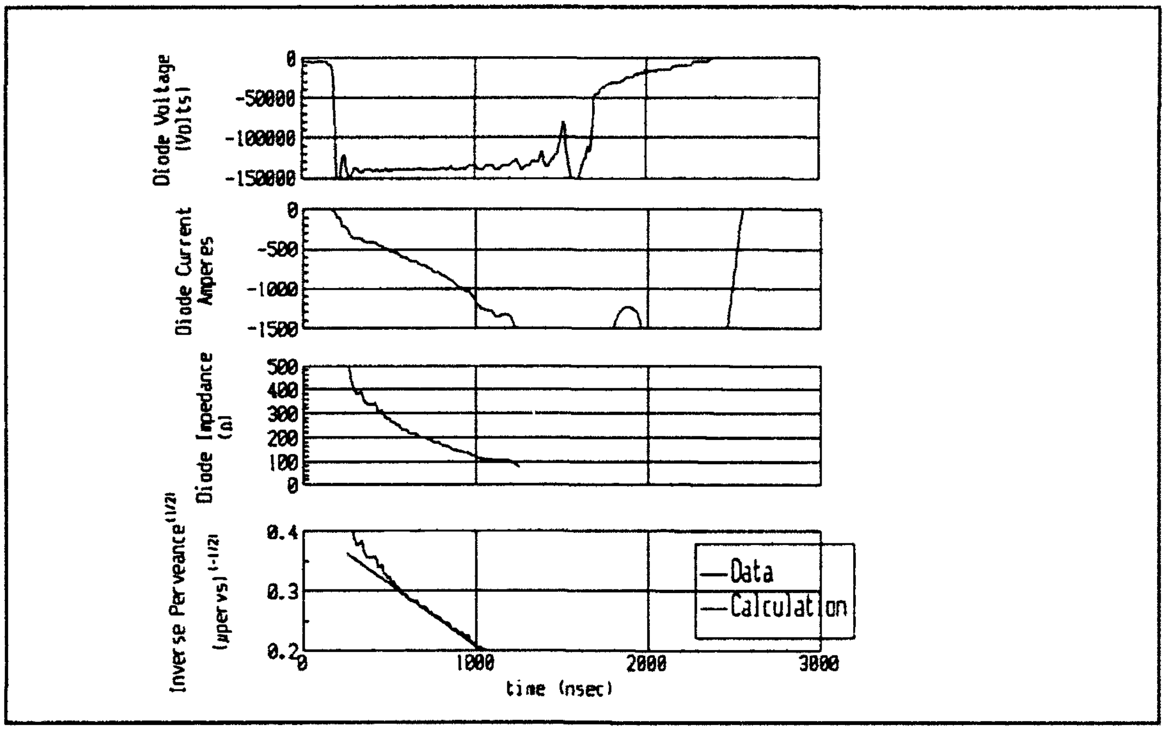

Figure 2. Data showing the performance of a 4.6 cm radius velvet cathode.

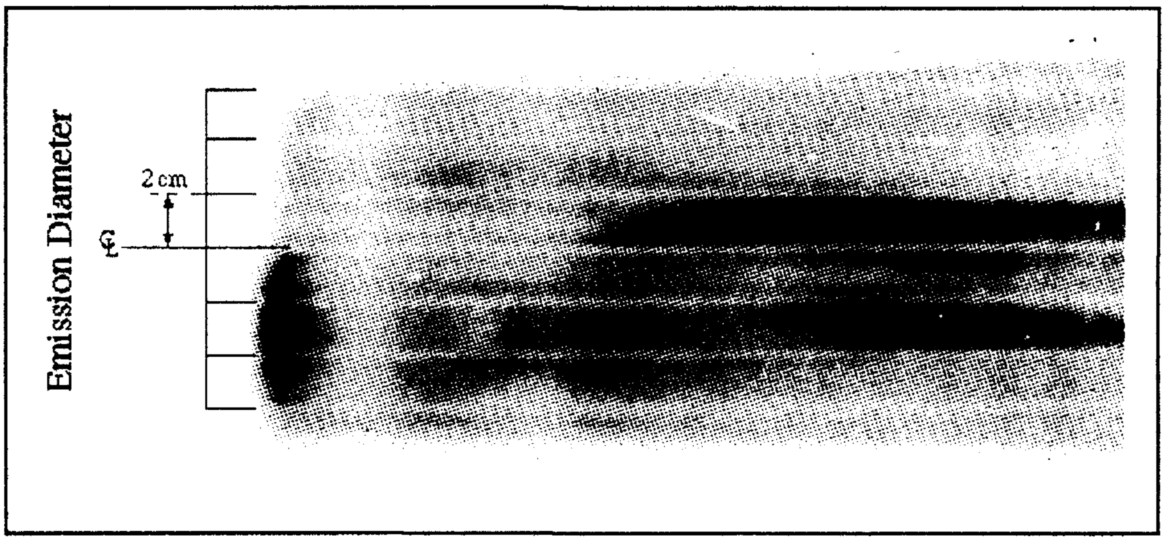

Figure 3. Streak photograph of the emission from a 4.6 cm velvet cathode. Time increases to the right.

lengthened pulse width were completed prior to the routine pulse power operation. This was again an effort to condition the cathode by removing contaminants from the vacuum diode in a fashion that would not impact the overall operation of the CsI cathode.

Initially a 6.85 cm radius emitting surface was used with a 5 cm radius aluminum mask on the anode. The emitted current showed that the cathode was not obeying the Child-Langmuir relationship, that is, the effective emitting area was larger (r = 7.9 cm) than the geometric area (r = 6.85 cm) of the carbon. However, even with this additional emission the diode still did not suffer from diode closure for several microseconds, if at all. Sample voltage, current, impedance and the inverse ratio of perveance versus time data are shown in Figure 4. The diode closure velocity was found to be < 0.3 cm/μs. The diode did finally close when the pulse power was applied for approximately 5 μs. However, on inspection of the cathode, aluminum was found plated on the cathode at positions corresponding to the anode mask radii. The plated aluminum was due to blow off from the anode mask, and likely resulted locally in a totally different emission process than was occurring in the pure CsI dominated portion of the cathode.

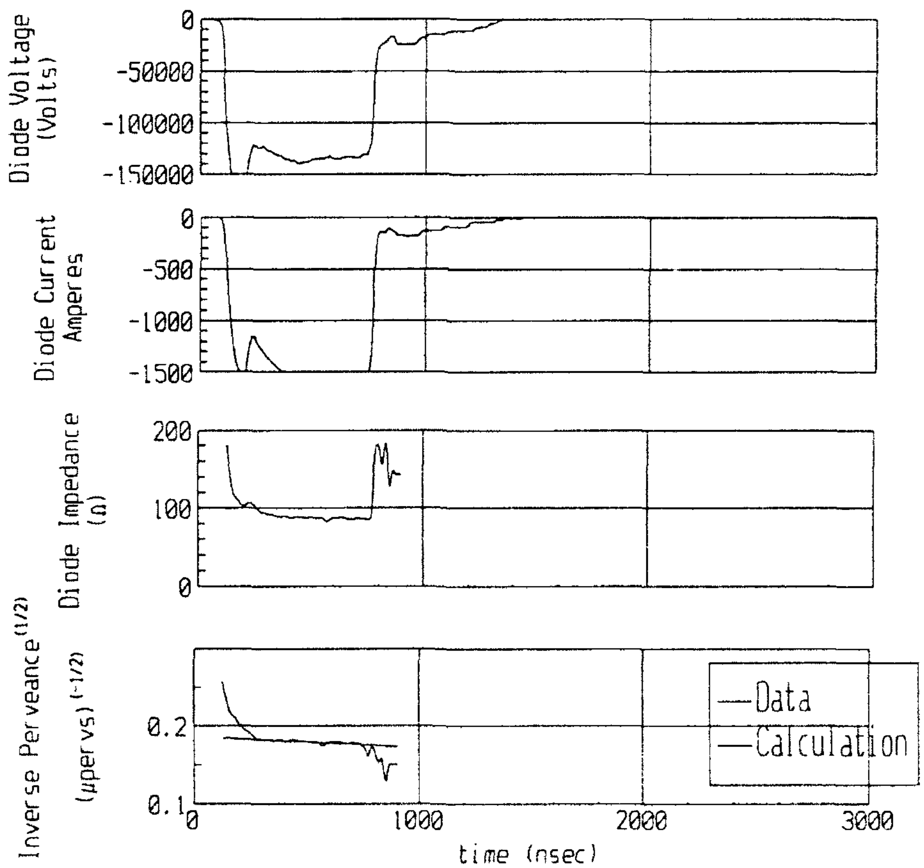

Figure 4. Data showing performance of a 6.85 cm radius CsI cathode.

This result indicated that if a smaller cathode was used without the anode mask on the 7.5 cm radius anode screen, aluminum plating of the cathode should not be a problem. As part of the hardware modification required to implement this change a series of spacer rings were built to enable recessing the emission surface below the corona bushing. This was done to test the idea that ultra-violet (UV) photons from the CsI [Ref.6] plasma were generating photo-electrons from the corona bushing, thus increasing the effective emitting area. Sample voltage, current, impedance and perveance versus time data are shown in Figure 5 for the new smaller cathode. Comparison of streak photographs of the 4.6 cm cathode flush with the corona bushing and when recessed from the corona bushing by several millimeters (mm) were recorded. A sample streak photograph when the emitting surface is recessed by 12 mm is shown in Figure 6. Notice that emission area is close to the geometric radius of the emitter when the emission surface is recessed. The change in effective diameter of the recessed emitting surface was consistent with UV line-of-sight from the cathode surface during emission from the corona bushing. Copious quantities of UV emission appear to accompany the CsI plasma production; it is beneficial to creating high-current density, space-charge-limited electron beams, but may be detrimental to nonemitting materials nearby.

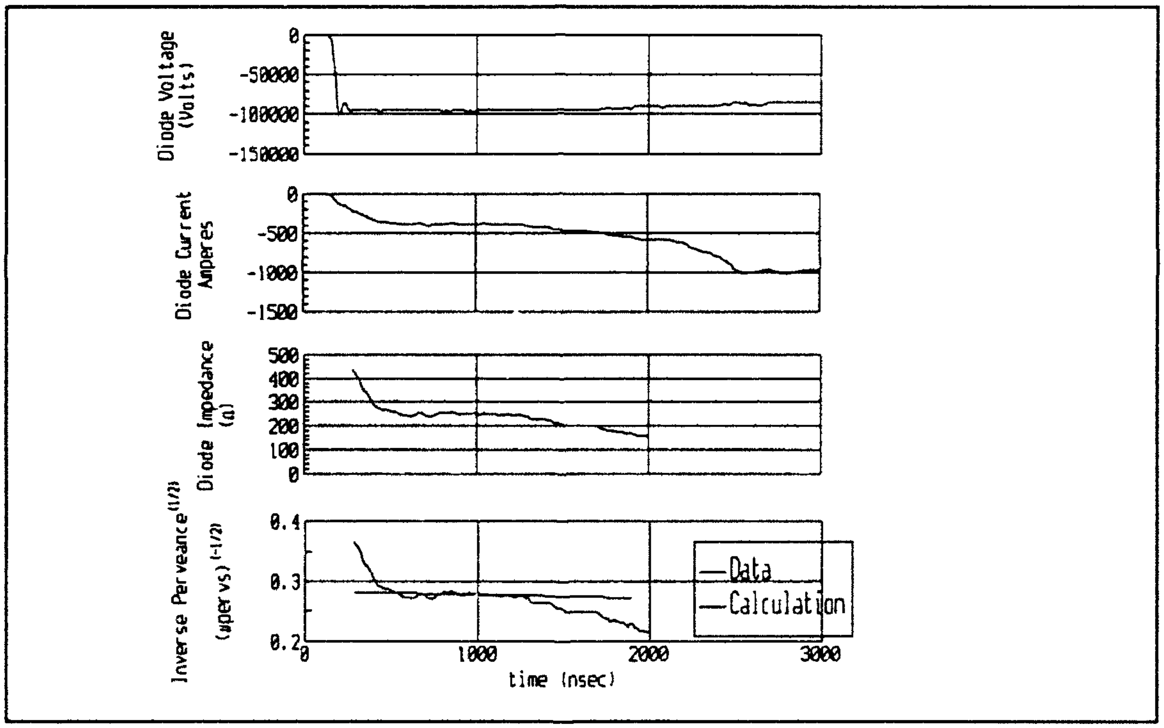

Figure 5. Data showing performance of a 4.6 cm radius CsI cathode.

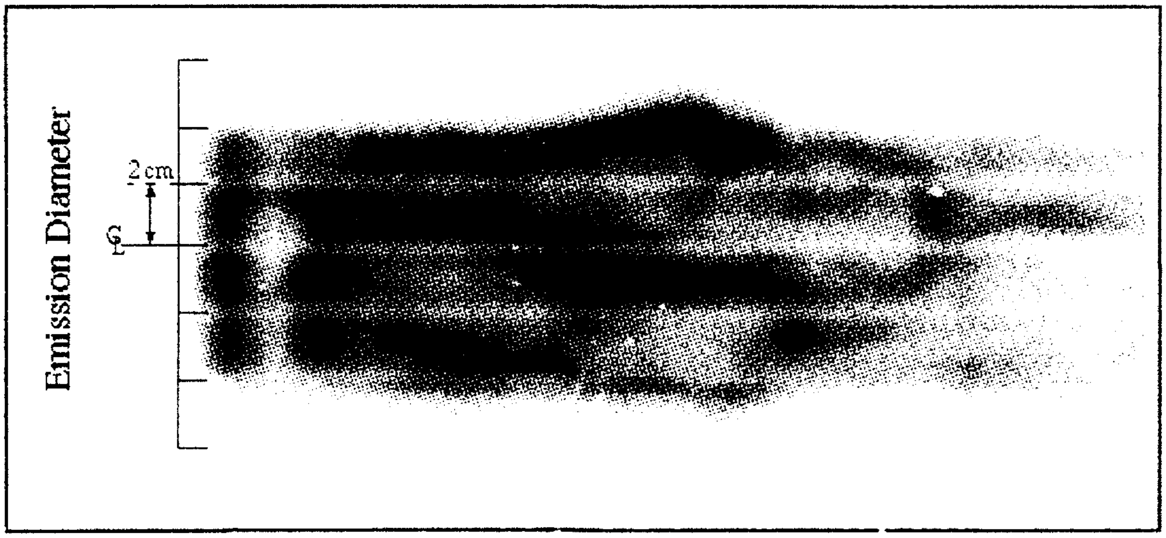

Figure 6. Streak photograph showing the emitted beam diameter from a 4.6 cm radius CsI cathode.

An overall comparison of the diode closure velocity versus applied diode voltage divided by the A-K gap for all the diodes used in these experiments and the parameter space for bulk graphite emitters is shown in Figure 7. It is not clear if this is the best presentation of the diode performance; however, it does present all the diode performance data on a common basis and does ease comparison. Clearly, the CsI cathode has the best performance in terms of the demonstrated closure velocity. This does not establish whether this slowed velocity is due to the increased ion mass. It is also unclear whether the closure velocity will stay truly constant as the applied electric field is increased. Clearly, at some high applied electric field stress the bulk graphite used as a support for the carbon fibers will begin to emit electrons with the same result observed in conventional bulk graphite cathodes.

4.0 CONCLUSIONS

The data presented in this paper indicate that the CsI cathode performs better in several ways than the present velvet cathode. The only area where the CsI cathode did not match the velvet was in the rise time of the current pulse. The rise time may be controlled by the packing distribution of the carbon fibers, which will be investigated in future work. It is still not fully understood why the CsI salt reduces the diode closure rate, and if the conditioning scheme is removing any contaminants. Plans have been made to further characterize the performance of the CsI cathode by investigating the response of the unpainted carbon fibers, replacing the stainless steel anode mesh with another material which is less susceptible to plasma formation, eliminating the aluminum corona bushing as a possible source of photoelectrons, and investigating the diode closure at higher electric fields. Regardless of these future investigations it is clear that the CsI cathode will be a useful option in future operations of the SCO in long pulse (~ 1 μs), repetitive pulse operation (tens of pulses per second).

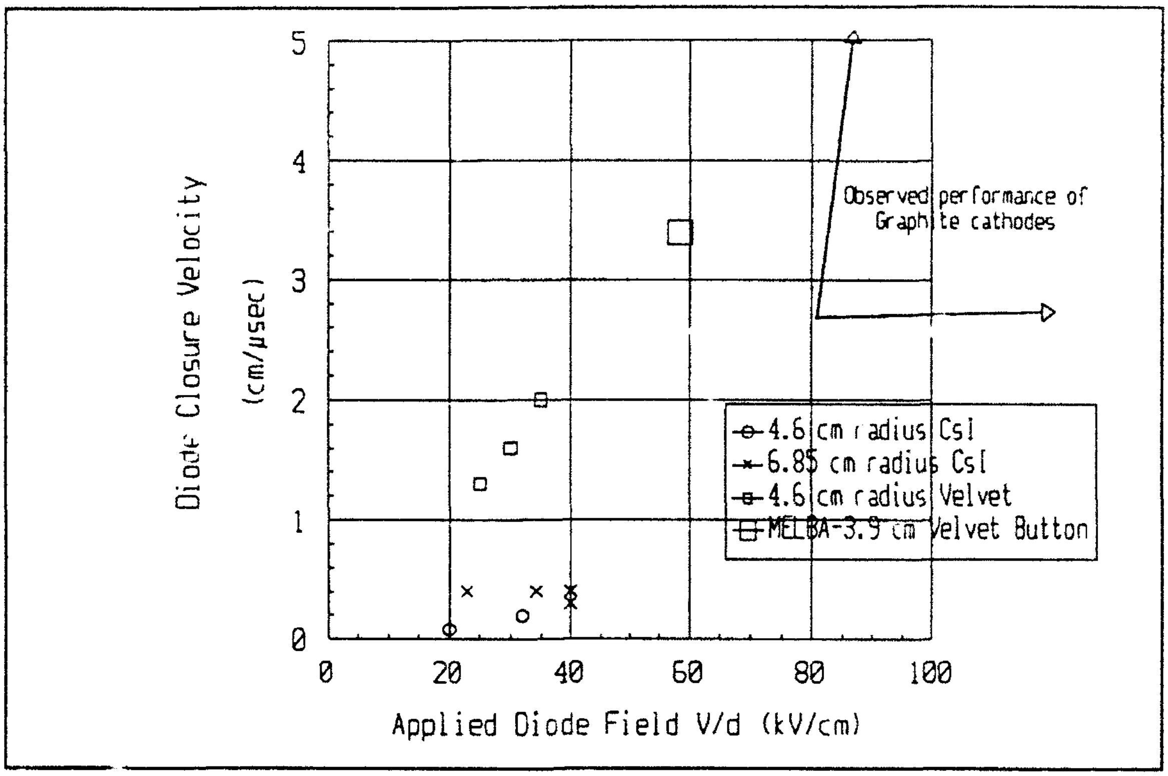

Figure 7. Comparison of diode closure rates as a function of applied electric field.

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